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A FREQUENCY DOMAIN TECHNIQUE FOR IMPROVING SOUND FIELD REPRODUCTION

by

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November 1988

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Farnborough, Hants

R O Y A L   A E R O S P A C E   E S T A B L I S H M E N T

Technical Memorandum MM 10

Received for printing 9 November 1988

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SUMMARY

This Memorandum describes a method for minimising the third-octave errors existing between a target sound field and its reproduction elsewhere. The spectrum is modified iteratively by the error spectrum and a new time history is produced.

This method of operating in the frequency domain is essentially the dual of the method described in Technical Memorandum FS(F) 679, which used digital filtering in the time domain.

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1 INTRODUCTION

An earlier Memorandum[1] showed how the reproduction of a target sound field could be improved at a remote replay station by digital filtering in the time domain. As stated, the process was effective, but was inefficient in computer storage and very time-consuming.

This Memorandum deals with a solution to the same problem in the frequency domain - as expected, it is neater, faster and uses less disc storage.

2 METHOD

2.1 Principle of method and general remarks

The technique in the frequency domain is the dual of that in the time domain. The Discrete Fourier Transform (DFT) of the target time history is obtained and stored on disc. A third-octave spectrum of the system error (*ie* between the target time history and the response of the sound system when excited by it) is used (not in real time) to modify the above DFT on disc and so obtain an inverse DFT that is then sent to the sound system as a synthetic input causing a smaller system error to be generated. The above process may then be repeated to reduce the error still further. It should be noted that in the earlier method the time history was filtered sequentially, one second at a time, with final retention of only the central portions of each. In the present method an entire time history (within necessary practical limitations) is processed as an irreducible segment.

The necessary inversion of a DFT in the process raises points of interest relevant to accuracy. There will be inevitably in the resulting inverse DFT some components of time history that can be attributed to spurious spectral components in the forward DFT, as well as those that are due to its 'true' components. These spurious components, due to windowing in both time and frequency domains, are indistinguishable from the true components and will corrupt to some degree the final result.

The DFT handles a finite number of data samples in both time and frequency domains. Sampling in time means that an infinitely long time history becomes truncated, while frequency sampling implies that this truncated time history is itself periodic in time. This means that the inverse DFT (*ie* the new synthetic input referred to above) will be heard as a repetition of the truncated time history. However, in general, the truncation length of the time history will not coincide reasonably with complete wavelengths of any dominant modes of the original aircraft noise, which is highly deterministic in the case of

helicopters. Consequently a more or less severe 'knock' may be heard at the points of discontinuity between successive outputs of the truncated series. Although the knock may be alleviated or be made audibly negligible by suitably 'trimming the ends' to match reasonably well, it is important to realise that the spectral components present in the forward DFT contain the frequencies responsible for the knock in the first place, so that if present originally (by bad or indeed inevitable choice of truncation length), they will remain to be included in the processing along with the 'true' components.

Another source of error is the windowing in frequency that occurs because the method inherently depends on external measurements of noise components within third-octave bands leading to certain spectral components being modified in magnitude.

If it were the case that the inversion was of an unmodified spectrum (a pointless exercise), then the errors introduced into the spectrum by the forward DFT (caused by the time-windowing of the target time history) would not cause the resulting output time history to be anything other than identical to the input, over the truncation length.

However, the modification of a third-octave-wide portion of the target spectrum must be seen as multiplication of the spectrum by a frequency window, a process whose inversion involves convolution in the time domain of the ideal (modified) output time history and an impulse response characterised by the bandwidth of the actual third-octave band being considered. Some error of this origin must be expected to be present in the final output and the above errors can be seen to produce unacceptable output time histories if the time window over which the DFTs are computed is as short as perhaps 1 second. In that case too much of the final output is being contaminated by the 'end effects', and it is necessary to extend the time window to, say, 16 seconds. However, this brings further difficulties, because the length (*ie* number of points) of the DFT now becomes too big for the array processor (AP) to handle, and so a new suite of modules was written to enable 'long' DFTs to be processed in each direction, with third-octave modifications as required while in the frequency domain. It is a restriction of the method that file lengths must be a power of two, and it is also important that the repetitive nature of the file length of the noise should not be obtrusive to a listener - with this in mind the input and output time histories are of 16 seconds duration.

2.2 Procedural details of method

It should be noted that the general arrangement of computer equipment, sound reproduction system and lab-based helicopter fuselage remain exactly as described in Technical Memorandum FS(F) 679, and Fig 1 of the present document is only a very slightly modified version of Fig 2 in the earlier Memorandum.

The procedure that has been developed has involved writing program modules that execute inside the framework of the data analysis package 'DATS' (Prosig Limited). These are arbitrarily named GRANGT, GRANGH and GRANGW because of the essential algorithm found in Ref 2 (Fast Fourier Transform of Externally Stored Data, by N. M. Brenner, who acknowledged E. Granger's method).

An iteration is now described in terms of these modules.

(a) Forward DFT of I/P time history - obtained by executing GRANGT. The input file is a Real time history, sampled at 32 k samples/sec, stored on disc as (R*4) values.

The O/P file will be (C*8), *ie* complex pairs of (R*4) after GRANGT has performed the forward, full-range DFT. The line spacing of the output spectrum will be I/T Hz, where T is the input duration in seconds.

The input (Target) spectrum has to be obtained only once.

(b) Acquisition of 1/3 octave spectra of target and its return field are performed exactly as in Ref 1, *ie* the target file is output through the sound reproduction system and the resultant sound field measured remotely by a B/K 2131 Frequency Analyser at one-third octave resolution. At the same time, a similar measure of the target field is made, and the third-octave initial error spectrum obtained.

(c) Derivation of a spectral file modified by an auxiliary file - an auxiliary file is created by using the above error file to modify the initial weighting factors of unity that are to be used in the subsequent inverse DFT.

Provision is made for a common gain factor to be applied to all third-octave bands if this should prove necessary due to overloading or overflow in any part of the system.

It was found that convergence of the error was better if the change to the band weighting factors was made somewhat smaller than that which would be applied directly via the error file. This might incur an extra iteration, but this seems preferable to the alternative poor damping of

the error. In general, an initial factor of 0.5 has been satisfactory, with a possible increase to 0.75 as the error reduces.

Then the Target Spectrum that was obtained in (a) above is weighted by the auxiliary file, operating in third-octaves. This is done by running a module GRANGH.

(d) Production of next O/P file is by running module GRANGW on the modified spectrum of (c). This performs the inverse DFT and produces a modified time history of duration T second. The module GRANGW additionally converts the output data into (I*2) form that is required by the computer real-time output routines, thus saving processing time considerably.

(e) Acquisition of 1/3 octave spectrum of new return field is similar to (b) above, except that the file to be output is the modified time history found in (d) above.

The third-octave spectrum of the newly acquired sound field is subtracted from the target spectrum to obtain the current error spectrum.

(f) Continued iteration by repeating (c) to (e) above should reduce the final error to within acceptable limits.

3 RESULTS

The spectra of jet aircraft resemble that of random noise over a wide frequency range and it is possible to keep the gain factor higher when dealing with them compared with the case of helicopters with their more discontinuous and sharply peaked spectra.

Fig 2a shows the original error spectrum of the difference in cabin noise as recorded in a Harrier aircraft and its reproduction in the ground-based simulator. Fig 2b shows the final error spectrum after the iterative procedures described in this Memorandum.

Fig 3a&b are similar results obtained from an AEW Sea King helicopter.

4 CONCLUSIONS

It has been demonstrated that errors in the remote reproduction of sound fields may be reduced by an iterative off-line process that modifies the input spectrum as a function of the error spectrum.

Acknowledgment

The author wishes to acknowledge with gratitude the considerable efforts of Dr J. A. Chillery in developing the real-time computer system that has been built up in MM4 - previously FS(F) 4 - at RAE[3].

REFERENCES

No.	Author	Title, etc
1	J.B. Collister	A method of improving remote reproduction of a sound field by one-third-octave analysis and digital filtering. Technical Memorandum FS(F) 679
2	N. M. Brenner	Fast Fourier Transform of externally stored data. IEEE Transactions on Audio and Electroacoustics, Vol AU-17, No.2, June 1969
3	J.A. Chillery J.B. Collister	A practical helicopter cabin noise simulator. Paper presented at the Second IEE International Conference on simulators, University of Warwick, Coventry, UK, September 1986

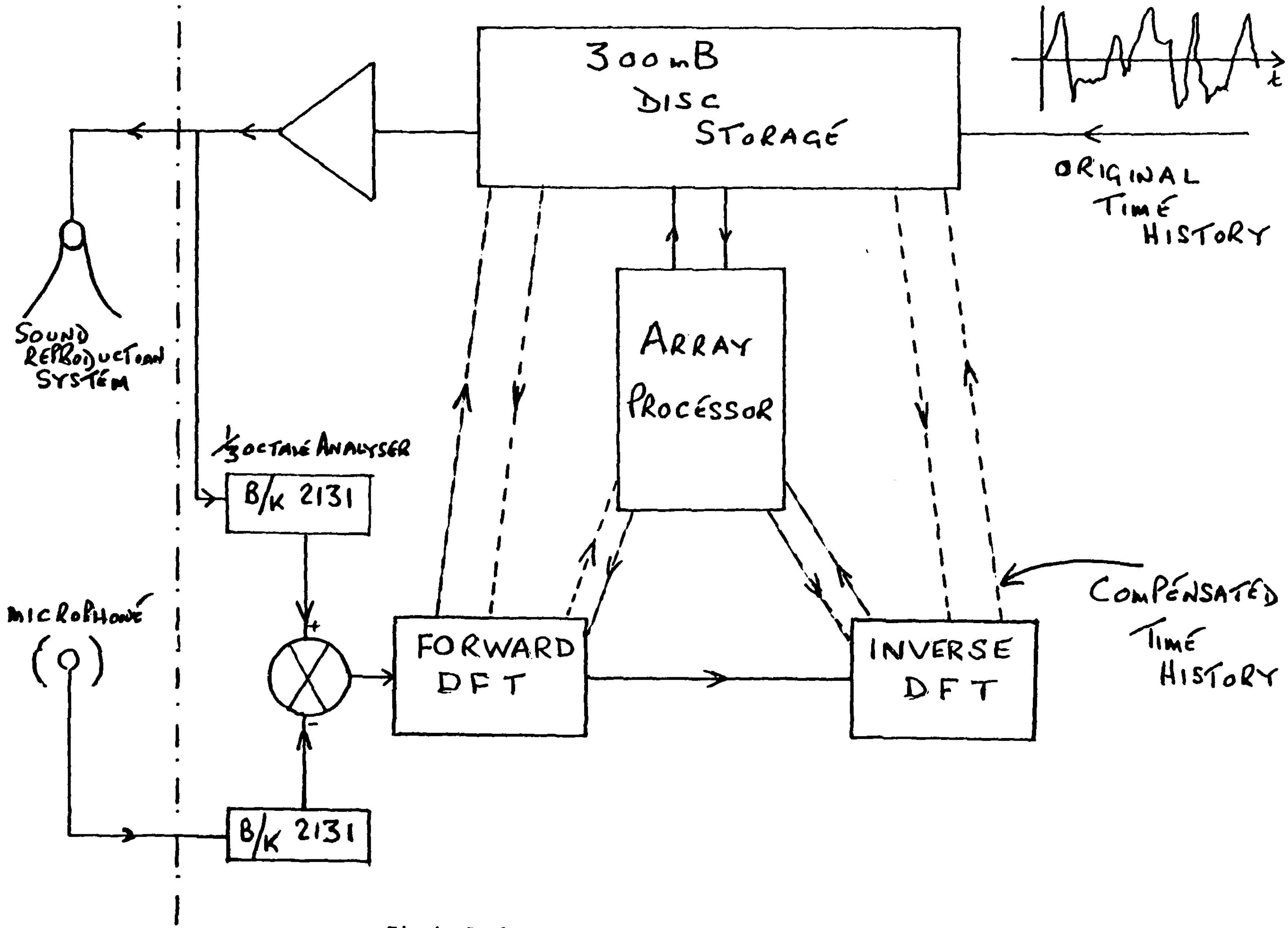
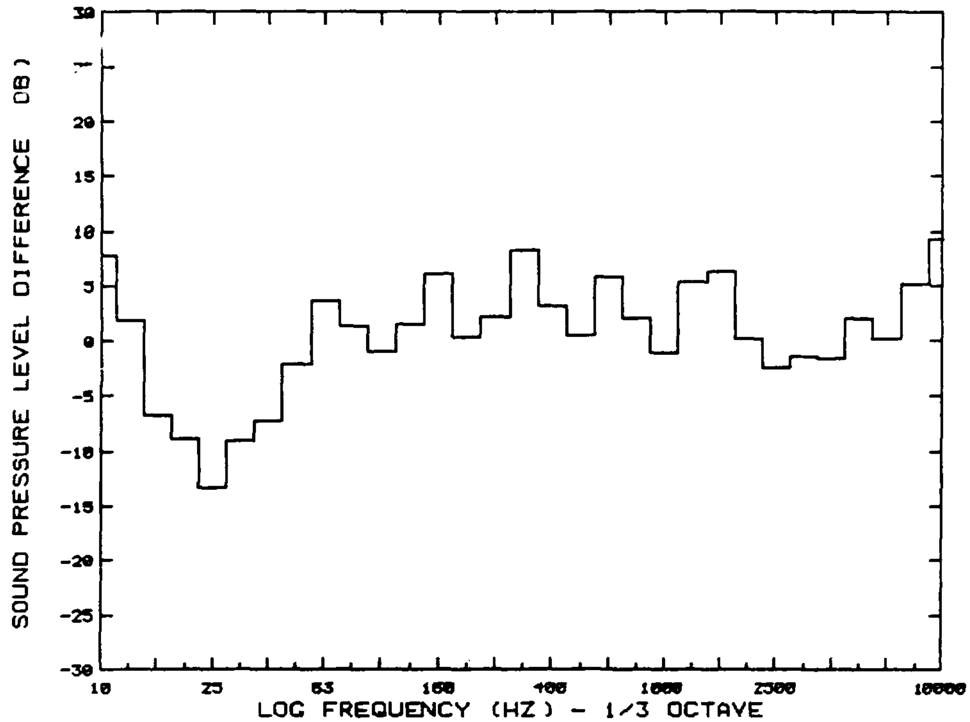


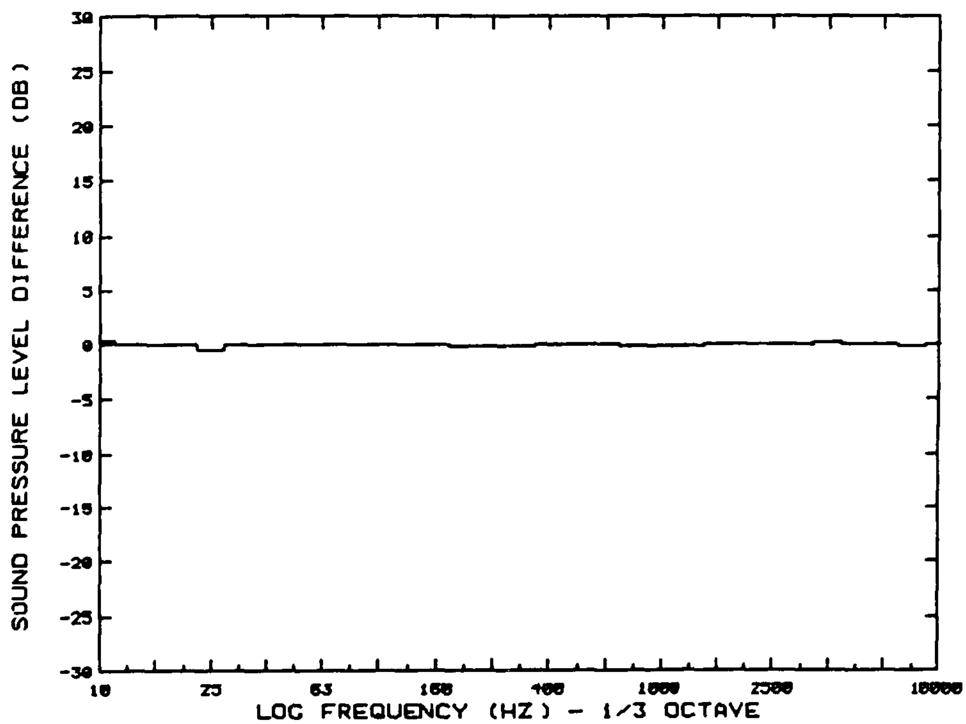
Fig 1 Implementation of compensation process

Fig 1

Fig 2a&b



(a) Unmodified



(b) After correction

Fig 2 Jet Aircraft noise error spectrum

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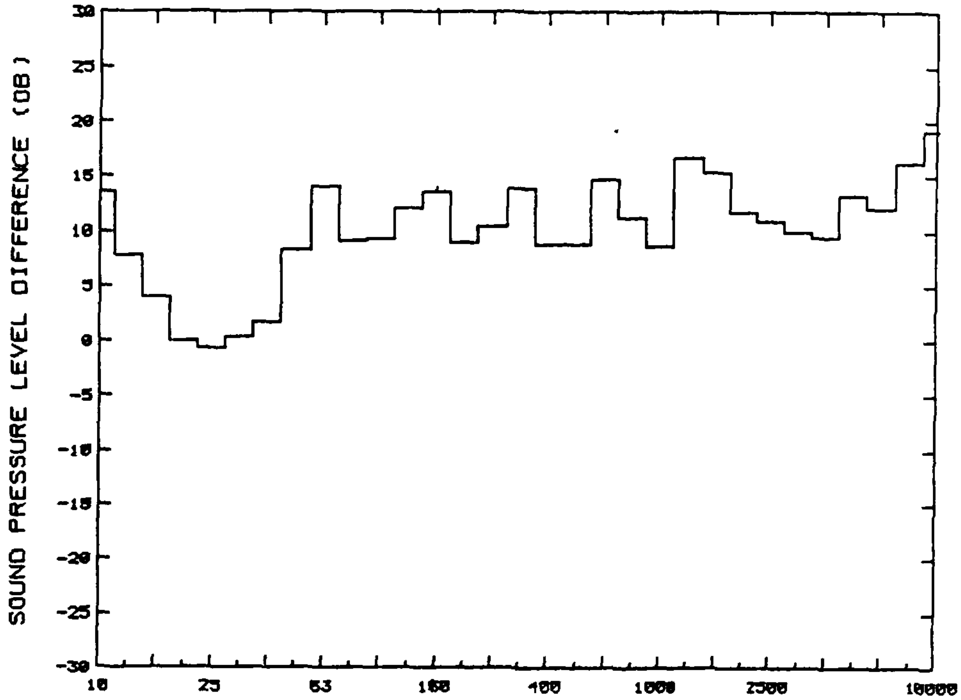
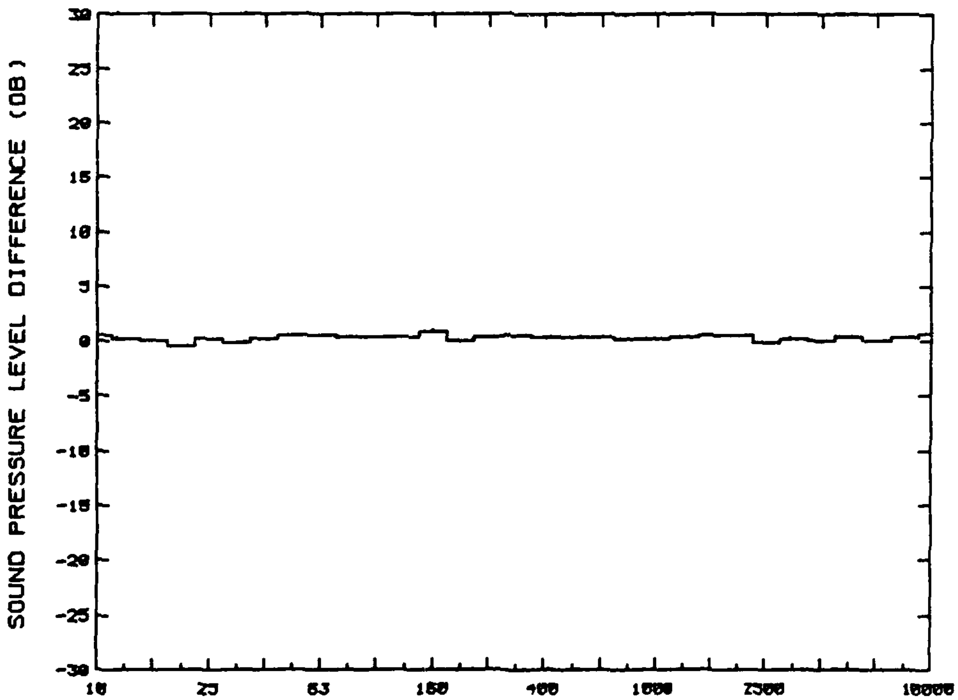


(a) Unmodified



(b) After correction

Fig 3 Helicopter noise error spectrum

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Overall security classification of this page

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1. DRIC Reference (to be added by DRIC)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification/Marking
	RAE TM MM 10		UNLIMITED

5. DRIC Code for Originator	6. Originator (Corporate Author) Name and Location
7673000W	Royal Aerospace Establishment, Farnborough, Hants, UK.
5a. Sponsoring Agency's Code	**6a. Sponsoring Agency (Contract Authority) Name and Location**

7. Title A frequency domain technique for improving sound field reproduction

7a. (For Translations) Title in Foreign Language

7b. (For Conference Papers) Title, Place and Date of Conference

8. Author 1. Surname, Initials	9a. Author 2	9b. Authors 3, 4	10. Date	Pages	Refs.
Collister, J.B.			November 1988	11	3

11. Contract Number	12. Period	13. Project	14. Other Reference Nos.

15. Distribution statement
(a) Controlled by –
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16. Descriptors (Keywords) (Descriptors marked * are selected from TEST)

Noise. Simulators. Processing. Great Britain, (UK)

17. Abstract

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